Annual Report
Fault Loading Processes in the New Madrid Seismic Zone

Paul Segall (650-723-7241, segall@stanford.edu)
Mark D. Zoback (650-725-9295, zoback@geo.stanford.edu)
Geophysics Department
**Stanford University**
Stanford, CA 94305-2215
Fax: (650) 725-7344

Abstract: Our understanding of the tectonic processes which generate earthquakes in intraplate settings such as the New Madrid seismic zone is severely limited. There are, as yet, no widely agreed upon mechanical models for intraplate earthquakes. We propose research in three areas: 1) formulation of tectonically reasonable finite element models for the generation of intraplate earthquake sequences with specific application to the New Madrid seismic zone; 2) analysis of the effects of glacial unloading on seismicity; and 3) analysis of GPS uncertainties and how these impact our ability to detect strain accumulation and differentiate between competing models of intraplate seismicity. Fully time dependent finite element models which incorporate spatial variations in material behavior, frictional fault slip, and realistic far-field boundary conditions will provide new insights into the mechanics of stress transfer and earthquake generation in intraplate, low strain-rate regimes. Our results will attempt to provide 1) mechanically reasonable models which can be used to interpret existing geological and geophysical data, especially geodetic data and 2) a firm physical basis for seismic hazard estimation in this region. Analysis of stresses induced by glacial advance and recession, and their effect on predicted seismic slip history, will help to test the hypothesis that the observed late-Holocene increase in slip-rate was triggered by post glacial rebound. Finally, we will investigate the uncertainties in Global Positioning System measurements within the New Madrid seismic zone. Based on this analysis, we will provide recommendations on measurement strategies necessary to detect strain accumulation and differentiate between competing hypothesis for the generation of intraplate earthquakes. We will consider the types of surveys (continuous vs. campaign), network geometry, duration of observations, and monument stability and how these factors effect uncertainty in strain-rate.

We consider models of intraplate earthquakes which include a weakness within the lower crust and applied far-field stress boundary conditions. The stress represents a perturbation in mechanical equilibrium, due perhaps to flexural stresses associated with post glacial rebound. For weak zones of finite extent subject to constant far-field stresses, the net fault offset remains finite as the weak zone relaxes. There are thus, at most, a finite number of large slip events. Preliminary calculations show that relaxation of the weak zone can generate a sequence of slip events, with maximum offset of ~5-10 m and moment magnitudes of 7.5 to 8.0, in agreement with estimates for the 1811-12 earthquakes (Figure 1). Surface strain-rates, as might be recorded by GPS measurements, are at or below the current detection level, consistent with current observations.
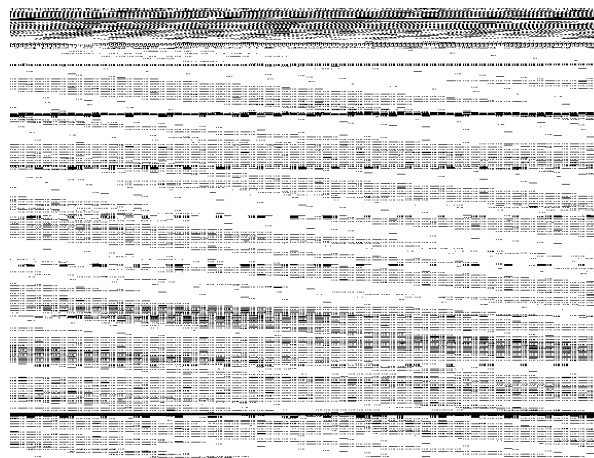
Figure 1. Cumulative moment (thin lines vs. time for a typical intraplate earthquake model. The moment release rate slows with time and recurrence interval for the largest events increases. Because details of the rupture process are not accurately modeled, only the dominant features of the model, i.e. the largest slip events, are considered (thick lines). Solid line shows results for $W_W = 75$ km, $d_W = 40$ km, $\tau^\infty = 60$ MPa, $\tau^{max} = 62$ MPa, and $\tau^{residual} = 50$ MPa. Dashed line shows results for $W_W = 75$ km, $d_W = 40$ km, $\tau^\infty = 25$ MPa, $\tau^{max} = 27$ MPa, and $\tau^{residual} = 15$ MPa.

Progress during the current reporting period was modest, primarily because the graduate student we had identified for this research decided to work on a different project. A Postdoc, Bjorn Lund,. has begun to work on the problem and we are confident can make rapid progress. In the mean time, Segall has made a thorough review of quasi-analytic (non-Finite Element Model) methods for computing the viscoelastic displacements and stresses associated with crustal faulting. We have identified apparently overlooked means for exactly inverting the Laplace transforms which are central to such methods. Displacements in the anti-plane strain and plane strain systems have been found in the Fourier domain, allowing rapid computation.

During this reporting period, Dr. Shelley Kenner, formerly of Stanford University and Caltech, joined the faculty at the University of Kentucky. She has purchased and installed workstations necessary for Finite Element computations. We have begun to consider methods for modifying our models of intraplate earthquakes to include temporally varying stresses due to glacial unloading. Post glacial rebound is the most plausible explanation for the acceleration of deformation during the late Holocene within the New Madrid Seismic Zone.

Other calculations, involving an inelastic crust at the frictional yield point, have elucidated the effect of glacial unloading on New Madrid seismicity ( ). Inclusion of a weak zone in the lower crust, as posited by Kenner and Segall (2000), shows a concentration of strain within the NMSZ. The timing is consistent with what is known about the onset of recent activity from paleoseismic studies.
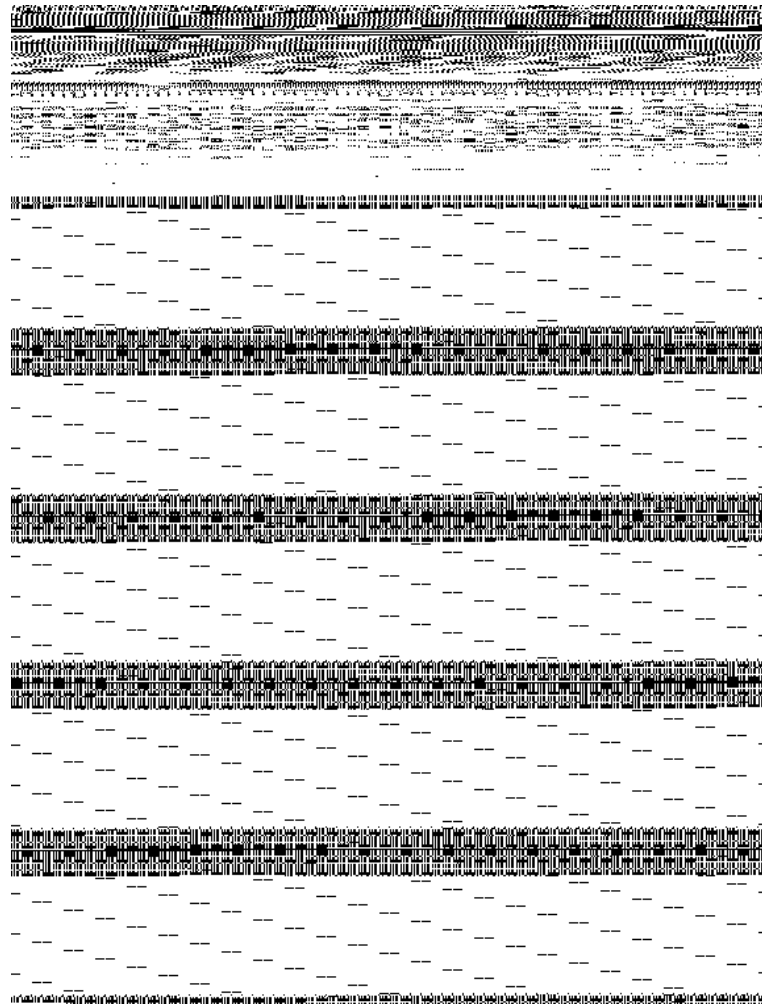
Figure 2. A preliminary result for the failed rift/hot spot model which shows predicted seismic strain-rates due to glacial unloading. (a) A localized zone of increased seismicity occurs near the NMSZ. The highest present-day modeled seismic strain-rates are 10^{-9} yr^{-1} which is 3 orders of magnitude higher than the background seismic strain-rate of 10^{-12} yr^{-1} representative for the eastern US. (b) Displays seismic strain-rates for the zone of highest predicted present-day seismicity. Note that seismicity was not observed either before glaciation or during the existence of the ice sheet. Seismicity commences around the time the ice load is removed.

Publications:

Kenner, S. and P. Segall, The Mechanics of Intraplate Earthquake Generation with Application to the New Madrid Seismic Zone, U.S.A., *Science*, v. 289, pp.2329-2332, 2000.

Grollimund, B. and Zoback, M D, Did deglaciation trigger intraplate seismicity in the New Madrid seismic zone? Geology, vol.29, no.2, pp.175-178, 2001.